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INTEGRAL and XMM-Newton observations of the low-luminosity and X-ray-rich burst GRB 040223^(*)

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Summary. — GRB 040223 was observed by INTEGRAL and XMM-Newton. GRB 040223 has a peak flux of $(1.6 \pm 0.13) \times 10^{-8}$ ergs cm⁻² s⁻¹, a fluence of $(4.4 \pm 0.4) \times 10^{-7}$ ergs cm⁻² and a steep photon power law index of -2.3 ± 0.2 , in the energy range 20–200 keV. The steep spectrum implies it is an X-ray-rich GRB with emission up to 200 keV and $E_{\text{peak}} < 20$ keV. If E_{peak} is < 10 keV, it would qualify as an X-ray flash with high-energy emission. The X-ray data has a spectral index $\beta_x = -1.7 \pm 0.2$, a temporal decay of $t^{-0.75 \pm 0.25}$ and a large column density of 1.8×10^{22} cm⁻². The luminosity-lag relationship was used to obtain a redshift $z = 0.1^{+0.04}_{-0.02}$. The isotropic energy radiated in γ -rays and X-ray luminosity after 10 hours are factors of 1000 and 100 less than classical GRBs. GRB 040223 is consistent with the extrapolation of the Amati relation into the region that includes XRF 030723 and XRF 020903.

PACS 98.70.Rz – γ -ray sources; γ -ray bursts.

PACS 95.55.Ka – X- and γ -ray telescopes and instrumentation.

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1. – Introduction

The prompt emission from GRBs and the afterglow give valuable information on the radiation processes and the environment. There is much evidence that the γ -radiation

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originates from dissipative processes in a relativistically expanding plasma wind with either shocks or in magnetic reconnection. In addition to GRBs, x-ray flashes (XRF) have been identified as a class of soft bursts that are very similar to GRBs (*e.g.* [2]). There seems to be a continuum of spectral properties for XRFs, X-ray-rich GRBs and classical GRBs and it is probable that they have a similar origin [20].

ESA's International Gamma-Ray Astrophysics Laboratory *INTEGRAL* [31], launched in October 2002, is composed of two main coded-mask telescopes, an imager IBIS [28] and a spectrometer SPI [29]) coupled with two monitors, one in the X-ray band and in the optical band. The two main instruments on board have coded masks, a wide field of view and cover a wide energy range (15 keV–8 MeV). The IBIS instrument consists of two independent solid-state arrays ISGRI and PICsIT, optimised for low and high energies, respectively. The ISGRI detector of IBIS consists of an array of 128×128 CdTe crystals sensitive to lower-energy gamma-rays [12] and is most sensitive between 15–300 keV. The mask is located 3.4 m above the detector plane. The SPI detector plane consists of an array of 19 germanium detectors surrounded by an active anticoincidence shield of BGO and imaging capabilities are achieved with a tungsten shield located 1.7 m from the Ge array. SPI is sensitive from ~ 20 keV–8 MeV.

INTEGRAL has a burst alert system called IBAS (*INTEGRAL* Burst Alert System [14]). *INTEGRAL* has detected and localised 21 GRBs to an accuracy of a few arcminutes using IBAS. Most of these bursts are very weak, *e.g.* [16]. SPI light curves and spectra of some of the bursts are publicly available [33]. Some bursts such as GRB 030329 are less luminous in γ -rays than the standard value of $\sim 10^{51}$ ergs [3]. The bursts GRB 980425 and GRB 031203 are in a separate class of sub-energetic events [21, 25, 30].

Here we report on observations of the prompt emission of GRB 040223 with *INTEGRAL* and the afterglow with XMM-Newton. The afterglow was not detected in the optical or near infrared [26] probably because of the large absorption associated with the high column density (sect. 2). No radio emission was detected from the afterglow about one day after the burst [23].

2. – Data analysis and results

GRB 040223 was detected by the *INTEGRAL* burst alert system IBAS [14] and the location rapidly distributed [10]. The IBIS light curve is given in fig. 1a and does not include two very weak emission pulses at about -80 s and -180 s. The weak emission was also detected with SPI. GRB 040223 is in the long duration class with a well-resolved pulse (fig. 1 a). The IBIS light curve was denoised with a wavelet analysis [19] and the risetime, fall time and FWHM of the pulse are 19 s, 22 s, and 13 s, respectively. GRB 040223 fits onto the part of the timing diagram [13] for long, slow bursts consisting of only a few pulses. The IBIS data was divided into two energy channels, *i.e.* 25–50 keV and 100–300 keV. The cross-correlation analysis [17, 22] was performed between the two channels and the lag was determined to be 2.2 ± 0.3 s which is longer than observed in most GRBs [17].

The IBIS spectral analysis was performed using the method described for GRB 040106 [16, 6]. The IBIS data, in the range 20 to 200 keV, is well fit by a single power law with photon index -2.3 ± 0.2 with a reduced χ^2 of 1.01 and 20 degrees of freedom (d.o.f.) (fig. 1b). The quoted errors are at the 90% confidence level. The peak flux is $(1.6 \pm 0.13) \times 10^{-8}$ ergs cm $^{-2}$ s $^{-1}$ in the brightest second and fluence $(4.4 \pm 0.4) \times 10^{-7}$ ergs cm $^{-2}$. The spectral results obtained with SPI are consistent with IBIS and γ -ray emission was detected to 200 keV.

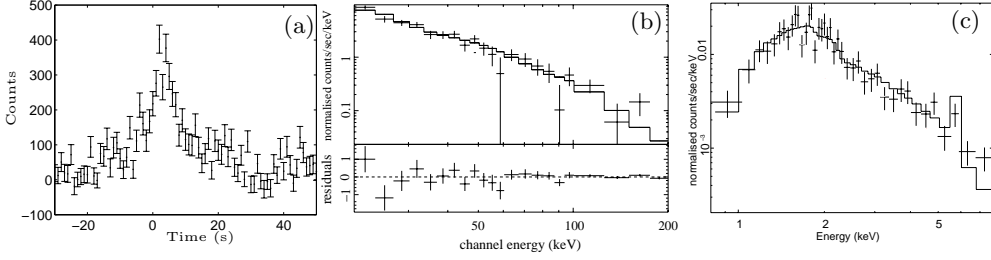


Fig. 1. – a) IBIS lightcurve of GRB 040223 in the energy range 15–200 keV and zero time is the IBAS trigger at 13:28:10 UTC. b) IBIS spectrum of GRB 040223 fit by a power law model from 20–200 keV. Upper panel: data and best fit model. Lower panel: residuals between the data and the folded model. c) EPIC spectrum of the GRB 040223 afterglow and its best fit absorbed power law model. The data points shown refer to PN and agree with the MOS data.

XMM-Newton observed the location of the GRB for 42 ks starting only 18 ks after the burst. A fading X-ray source was detected at RA = 16 h 39 m 30.17 s, Dec = $-41^{\circ}55'59.7''$ within the IBAS error region. The temporal decay of the X-ray afterglow ($F_{\nu}(t) \propto t^{-\delta}$) was fit by a power law with index $\delta = -0.7 \pm 0.25$ by Gendre *et al.* (2004) [8]. Only 17 ks of the light curve was used in the analysis because of contamination. Our analysis is consistent with this result.

We obtained afterglow spectra from the PN and MOS Cameras [27] after standard data screening. The three spectra in the energy range 0.2–10 keV were well fit by a power law $F_{\nu} \propto \nu^{-\beta_x}$ where the spectral index $\beta_x = 1.7 \pm 0.2$ with reduced χ^2 of 1.29 for 111 d.o.f. (fig. 1c). The absorption column density has a high value of $N_H = 1.8 \times 10^{22} \text{ cm}^{-2}$ and exceeds the galactic value in this direction of $6 \times 10^{21} \text{ cm}^{-2}$.

3. – Discussion

It is suspected that the nearest and most frequent bursts have been missed because they are either intrinsically sub-energetic or off-axis or both [17, 19]. In an extensive luminosity-lag study [17] a sub-sample of bursts was identified that had few wide pulses, long lags, soft spectra and a log N -log S distribution that approximates to a $-3/2$ power law. GRB 040223 consists of a slow pulse with a long lag of 2.2 ± 0.3 seconds, lies near the supergalactic plane with coordinates 179° , 24° and seems to be a member of the sub-sample.

There are no direct measurements of the redshift to GRB 040223 and indirect, model-dependent, distance indicators must be used. The luminosity-lag relationship was modified [17] to include GRB 980425 and the peak luminosity is given by

$$L = 7.8 \times 10^{53} \left(\frac{\tau_{lag}}{0.1 \text{ s}} \right)^{-4.7}$$

for $\tau_{lag} > 0.35$ s. The peak luminosity is $3.8_{-1.7}^{+3.8} \times 10^{47} \text{ ergs s}^{-1}$ for the lag of 2.2 ± 0.3 s. The redshift to the source is $z = 0.1_{-0.02}^{+0.04}$ when the peak flux of $(1.6 \pm 0.13) \times 10^{-8} \text{ ergs cm}^{-2} \text{ s}^{-1}$ is combined with the peak luminosity. The fluence gives a total isotropic γ -ray luminosity (E_{ISO}) of approximately 10^{49} ergs which is about three orders of magnitude less than classical GRBs. GRB 040223 is sub-luminous in γ -rays by a large factor.

The γ -ray luminosity may also be obtained using the Amati relation [1]. The measured photon index is well outside the normal range [18] for α of $-3/2$ to $-2/3$ and the value of -2.3 ± 0.2 is remarkably similar to the spectral index β above the break energy (E_0) that has a value typically between -2 and -2.5 . The slope is steeper than the value of -1.9 reported for the weak INTEGRAL burst GRB 040403 [15]. GRB 010213 also has a very soft spectrum with a photon index of -2.14 and a low value for E_0 of 4 keV [2]. If it is assumed that $\beta = -2.3 \pm 0.2$, then E_0 must be less than 20 keV to be outside the IBIS energy range. The peak energy E_{peak} is given by $(2 + \alpha) E_0$ and hence $E_{\text{peak}} = E_0/2$, for a value of $\alpha = -1.5$. Using the Amati relationship [9], the value of E_{ISO} is $< 2 \times 10^{50}$ ergs assuming that the rest frame value of E_{peak} is < 20 keV. The two indirect distance indicators yield consistent results and show that GRB 040223 lies on or near the extrapolation of the Amati relation from classical GRBs to include XRF 030723 and XRF 020903. The Yonetoku relation [32] between peak luminosity and E_{peak} also yields results consistent with the above conclusions. GRB 040223 is an X-ray-rich burst with a low value of E_{peak} and it would qualify as an XRF if E_{peak} is < 10 keV [2, 11].

The X-ray flux after 10 hours is $2.4 \pm 0.4 \times 10^{-13}$ ergs $\text{cm}^{-2} \text{s}^{-1}$ in the $2\text{--}10$ keV region. The X-ray luminosity of GRB 040223 is 6×10^{42} ergs s^{-1} and is about 2 orders of magnitude fainter than observed from classical GRBs [3]. It is interesting to note that the X-ray and γ -ray luminosities of GRB 040223 are only a factor of 2 and 5 weaker than the sub-energetic burst GRB 031203 [21, 25]. The major difference between the two bursts is that GRB 031203 has $\alpha = 1.65 \pm 0.1$ and $E_0 > 180$ keV [21] whereas GRB 040223 has a steeper index of -2.3 ± 0.2 and $E_0 < 20$ keV.

The X-ray afterglow of GRB 040223 has a slow decline ($\delta = -0.75 \pm 0.25$) that is similar to slow declines of many GRBs [5, 7] including $\delta = -1.0 \pm 0.1$ for XRF 030723 [4] and $\delta = -1.1$ for XRF 020903 [20, 24]. The X-ray and γ -ray luminosities of GRB 040223 and XRF 030723 are very comparable. It seems likely that GRBs are viewed from inside the jet whereas XRFs are viewed from the side and have lower luminosities, longer lags and slower and fewer pulses [11, 13, 17, 19].

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